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A Deterministic Quantum Hash Framework for Multi-Scale Physical and Informational Systems

Abstract

A deterministic framework is defined for constructing a quantum hash as a hybrid physical-informational descriptor applicable across multiple scales, from macroscopic physical systems to biological structures.[file:202] To make the framework empirically reproducible, each theoretical dimension is anchored to real and reliable data sources, including metrological constants repositories, astronomical reference systems, quantum-state reconstruction datasets, and biological provenance databases.[file:202][page:1][web:207][web:211] This data-grounded formulation clarifies which observable indicators instantiate each part of the model, how strongly each part is covered by currently available data ecosystems, and which dimensions already admit high-precision operationalization versus those that remain class-dependent or proxy-based.[file:202]

1. Introduction

The quantum hash framework is designed as an informational construct built on top of standard physical observables and structured descriptors rather than as a new physical observable.[file:202] Its practical value depends on whether the model components can be connected to real sources of mass, energy, state structure, entropy, time indexing, causal relation, and provenance metadata in a way that is reproducible across institutions and implementations.[file:202]

A data-anchored implementation therefore requires three tasks: mapping each theoretical dimension to reliable source families, checking the coverage of each dimension across realistic use cases, and documenting precisely which observed indicator represents which part of the model.[file:202]

2. Core Operational Dimensions

The framework is anchored through the following dimensions:[file:202]

- State representation $\rho_o(t)$.
- Effective observable summary $X_o(t) = \text{Tr}(\rho_o \hat{H}_{\text{eff}})$.

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- Entropy and normalized entropy $S(\rho_o), S_{\text{norm}}$.
- Energy scale E_o .
- Deterministic temporal index $T(t)$.
- Causal descriptor $\mathcal{C}(t)$.
- Structured provenance metadata $\mathcal{M}_o$.[\[file:202\]](#)

These dimensions are data-linkable, but not all of them have the same level of direct observability across all domains.[\[file:202\]](#)

3. Mapping to Reliable Data Sources

3.1 Source Families

The model can be anchored to four major classes of trusted sources:[\[file:202\]](#)

- **Physical constants and metrology sources**, especially NIST CODATA, for constants such as the speed of light and energy-conversion standards.[\[page:1\]](#)[\[web:210\]](#)[\[web:216\]](#)
- **Astronomical and astrophysical reference systems**, such as NASA/JPL Solar System Dynamics and related catalog infrastructures, for mass and scale references in macroscopic systems.[\[page:0\]](#)
- **Quantum-state reconstruction and tomography datasets**, including direct density-matrix or shadow-tomography data sources, for operational estimation of ρ_o and derived entropy quantities.[\[web:207\]](#)[\[web:209\]](#)
- **Biological and provenance repositories**, including NCBI Datasets, NCBI Entrez-linked resources, UniProt-linked ecosystems, and structured scientific repositories such as Zenodo, for biological descriptors, metadata, and pipeline traceability.[\[web:211\]](#)[\[web:217\]](#)[\[web:214\]](#)

3.2 Dimension-to-Source Mapping

Model dimension	Primary real sources	Supporting sources	Operational meaning

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E_o	NIST CODATA constants and energy-equivalent references [page:1][web:210][web:216]	NASA/JPL scale references for astronomical masses [page:0]	Physical or effective energy-scale anchor
$\rho_o(t)$	Quantum tomography and density-matrix reconstruction datasets [web:207][web:209]	Simulation outputs and experimentally reconstructed state matrices [file:202]	State configuration and probabilistic structure
$S(\rho_o), S_{\text{norm}}$	Derived from density-matrix datasets and entropy estimators [web:207][web:209]	Class-specific reference entropy tables [file:202]	Informational disorder and bounded complexity position
$X_o(t)$	Simulation datasets and operator-based computation pipelines [file:202]	Experiment-specific operator reconstructions, graph-based or field-based models [file:202]	Expected response under effective operator
$T(t)$	Instrument timestamps, simulation step logs, acquisition cycle records [file:202]	Institutional workflow timestamps and event counters [file:202]	Deterministic position in time or sequence
$\mathcal{C}(t)$	Workflow lineage records, process-dependency logs, causal relation tables [file:202]	Directed acyclic graph metadata in computational pipelines [file:202]	Admissibility or consistency of state relation
$\mathcal{M}_o$	NCBI Datasets, Entrez-linked records, Zenodo records, institutional metadata stores [web:211][web:214][web:217]	Internal protocol registries and simulation manifests [file:202]	Provenance, identity, and contextual reproducibility

This mapping shows that the framework is already strongly anchored for constants, scale, metadata, and state datasets, while operator-specific and causal dimensions often depend on domain-specific computational infrastructure.[file:202][web:210][web:211]

4. Coverage Assessment

4.1 Coverage by Dimension

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Coverage refers to whether a model dimension can be instantiated from currently available reliable sources without inventing unsupported surrogate quantities.[file:202] The coverage profile of the framework is as follows:[file:202]

Dimension	Coverage status	Typical accessibility	Coverage comment
E_o	High	Very high	Strongly covered by NIST CODATA and standard physical scaling references [page:1][web:210][web:216]
$T(t)$	High	Very high	Widely available from simulation logs, instrumentation, and workflow systems [file:202]
$\mathcal{M}_o$	High	High	Strongly covered by metadata repositories and structured dataset ecosystems [web:211][web:214][web:217]
$\rho_o(t)$	Moderate-to-high	Moderate	Well covered in quantum experiments and simulations, but not universally direct in all application domains [web:207][web:209]
$S(\rho_o), S_{\text{norm}}$	Moderate-to-high	Moderate	Strong when ρ_o is available or reconstructible, weaker when entropy is estimated indirectly [web:207][web:209]
$X_o(t)$	Moderate	Domain-dependent	Coverage depends on whether a class-specific $\hat{H}_{\text{eff}}$ is formally defined and computable [file:202]
$\mathcal{C}(t)$	Moderate	Domain-dependent	Feasible through workflow or lineage coding, but requires explicit institutional definition [file:202]

This profile indicates that the strongest current empirical anchors are those associated with constants, energy scale, time indexing, and structured provenance, while the effective-operator and causal dimensions require more domain-specific formalization.[file:202]

4.2 Minimal, Intermediate, and Expanded Coverage Modes

A **minimal coverage mode** is achievable with NIST constants, direct mass-energy scaling, deterministic timestamps, and structured metadata.[page:1][web:210][web:211] An **intermediate mode** adds tomography-derived or simulation-derived state representations and entropy estimators.[web:207][web:209] An **expanded mode** incorporates domain-specific effective operators, lineage-aware causal coding, biological sample repositories, and cross-pipeline provenance records.[file:202][web:214][web:217]

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5. Precise Indicator-to-Model Mapping

5.1 Indicator Dictionary

Indicator	Assigned model part	What it represents in the model	Source class
Speed of light c	Energy equation $E = Mc^2$	Fixed physical constant used for scale conversion	NIST CODATA [page:1][web:210]
Measured or catalog mass M_o	Energy scale E_o	Primary physical mass input for macroscopic scaling	Astronomical or physical reference systems [page:0][file:202]
Reconstructed density matrix	$\rho_o(t)$	Operational state representation	Quantum tomography datasets [web:207][web:209]
Probability vector over states	Approximate $\rho_o(t)$ in classical/hybrid cases	Normalized state configuration proxy	Simulation or informational datasets [file:202]
Von Neumann entropy	$S(\rho_o)$	Informational disorder of a density operator	Derived from reconstructed ρ_o [file:202][web:207]
Shannon or spectral entropy	Entropy surrogate	Disorder estimate when the system is not represented by a literal quantum density matrix	Derived from empirical state distributions [file:202]
Class-specific $S_{\max}$	Normalization factor for S_{norm}	Upper reference for bounded entropy scaling	Theory-guided or reference-table source [file:202]
Hamiltonian or effective operator expectation	$X_o(t)$	Scalar structural-dynamical system summary	Simulation or operator pipeline [file:202]
Timestamp or step index	$T(t)$	Deterministic time or sequence identifier	Instrument, simulation, or workflow logs [file:202]
Lineage or causal-validity code	$\mathcal{C}(t)$	Causal or admissibility descriptor	Workflow metadata or process graph records [file:202]

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Dataset ID, protocol, version, sample class	$\mathcal{M}_o$	Provenance context and reproducibility layer	NCBI, Zenodo, internal manifests [web:211][web:214][web:217]
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This dictionary makes the correspondence between observed variables and theoretical terms explicit and reduces ambiguity in implementation.[file:202]

5.2 Interpretation Precision

Not every indicator has the same degree of conceptual proximity to the theoretical object it represents.[file:202] The highest conceptual precision is achieved when ρ_o is a directly reconstructed density matrix, entropy is computed from its eigenvalue spectrum, mass or energy is directly measured or cataloged, and metadata come from structured provenance systems.[web:207][page:1][web:211] Precision is lower when classical probability vectors replace density matrices, when entropy is approximated by surrogate measures, or when $\hat{H}_{\text{eff}}$ is represented only through a heuristic operator score rather than through a formally defined class-specific operator.[file:202]

6. Results-Oriented Precision Paragraph

When anchored to currently available reliable sources, the framework exhibits its highest implementation precision in the energy-scale, temporal, and provenance dimensions, because these are strongly supported by mature standards and repositories such as NIST CODATA, structured logging systems, and stable metadata infrastructures.[page:1][web:210][web:211] The state and entropy dimensions can also be implemented with high precision in quantum-experimental and simulation settings where density-matrix reconstruction is available, especially through tomography or shadow-tomography style datasets.[web:207][web:209] The principal source of precision variability lies in the definition of the effective operator and the causal descriptor, since both depend more strongly on the application domain and on the formal quality of the local implementation.[file:202] In practical terms, the model is already highly precise as a deterministic multi-source descriptor in settings that combine metrological constants, direct mass-energy scaling, structured state reconstruction, and canonical metadata management, while its operator-sensitive explanatory richness increases further as the domain-specific formalization of $\hat{H}_{\text{eff}}$ improves.[file:202]

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7. Source-Aware Implementation Structure

A robust implementation should treat the source layer as part of the model itself rather than as an afterthought.[file:202] In practice, this means that each hash record should preserve the origin of the mass or energy value, the provenance of the state estimator, the entropy method, the definition of the effective operator, the time-index rule, and the metadata schema used to build the deterministic input.[file:202]

This source-aware design is particularly important because two implementations using the same conceptual equations can still produce different hashes if they draw from different source conventions, operator definitions, or metadata schemas.[file:202] Explicit source anchoring therefore improves not only reproducibility but also interpretability and cross-system comparability.[file:202]

8. Biological and Hybrid Extension

In biological and hybrid informational systems, the framework can be anchored through NCBI Datasets and associated Entrez-linked resources for structured sample or sequence context, together with non-sensitive aggregate descriptors and repository-managed provenance records.[web:211][web:217] In these contexts, the strongest anchors are usually metadata, lineage, experimental condition, and structured sample identity, while the effective-energy and entropy layers require more domain-specific conventions.[file:202]

Zenodo and similar scientific repositories can additionally support reproducible archiving of simulation manifests, operator definitions, entropy tables, and serialized parameter schemas, strengthening the provenance dimension of the model in computational workflows.[web:214]

9. Conclusion

The deterministic quantum hash framework can be anchored to reliable data sources with clear mapping from theoretical dimensions to observable indicators.[file:202] Current data ecosystems already provide strong support for constants, macroscopic scaling, timestamps, provenance metadata, and, in appropriate settings, state reconstruction and entropy estimation.[page:1][web:207][web:210][web:211] The most domain-sensitive dimensions remain the effective operator and the causal descriptor, but these can still be operationalized rigorously when local formal definitions are declared and versioned as part of the source model.[file:202]

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